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Multi-Modalities Sensor Science

Sailing He
KUNGLIGA TEKNISKA HOGSKOLAN

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Department of Electromagnetic Engineering,
School of Electrical Engineering, Royal Institute of Technology (KTH),
Stockholm 100 44, Sweden

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14. ABSTRACT

The proposed cross-discipline experimental study combines soft material science, laser spectroscopy, nano-technology, biophontics and multi-physics modeling to produce adaptable bio-nanostructure enhanced multi-mode sensor science.

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Final Report for SOARD Project

“ Multi-Modalities Sensor Science

Research goals

The proposed cross-discipline experimental study aims to combine soft material science, laser spectroscopy, nano-technology, biophotonics and multi-physics modeling to produce adaptable bio-nanostructure enhanced multi-mode sensor science.

1. Summary and significance of the stuies

1.1 A General Method for Designing a Radome to Enhance the Scanning Angle of a Phased Array Antenna

A phased array antenna has been widely used in mobile communications, satellite broadcasting, space probe communication, radar system and radio astronomy. In practice, the scanning angle of a phased array antenna is limited from -60o to +60o. A lens has been proposed for extending the scanning range of a phased array antenna with the help of some optimization algorithm. However this lens suffer some disadvantages: 1) the designing process of this Bucky-ball NIM lens is very complex. It requires an optimization process (over 8000 simulations have been run) to determine an initial 2D structure. 2) the relationship between the input beam produced by a PAA and the output beam steered by the radome is not linear or other relations that can be determined in advance. In many practical applications, it often needs a linear relationship between the input beam and the steered output beam.

In this project, we propose a general method to design an arbitrarily shaped radome which can extend the scanning angle of a phased array antenna through finite embedded transformation (FET). The main advantage of our method is that the relationship between the incident angle and steered output angle of the radome can be designed in advance (e.g., a linear relation can be achieved). Unlike a traditional FET, which is often applied onto a slab region, we first apply FET onto an arbitrarily shaped region to bestow the desired radome with an arbitrary shape. Two specific examples have been given to demonstrate our method. Numerical simulations show good performance of our radome.

1.2 Vectorial Electric field Monte Caro simulations for focused laser beams (800 nm- 2220 nm) in a biological sample

we develop a method that combines vectorial electric field Monte Carlo simulation with Huygens–Fresnel principle theory to determine the intensity distribution of a focused laser beam in a biological sample. The proper wavelengths for deep tissue imaging can be determined by utilizing our method. Furthermore, effects of anisotropic factor, scattering and absorption coefficients on the focal spots are analyzed. Finally, the focal beams formed by objective lenses with different values of numerical aperture are also simulated to study the focal intensity in the biological sample.

1.3 Experimental demonstration of a multiphysics cloak: manipulating heat flux and electric current simultaneously

Invisible cloaks have been widely explored in many different physical systems but usually for a single phenomenon for one device. In this Letter we make an experimental attempt to show a multidisciplinary framework that has the capability to simultaneously respond to two different physical excitations according to predetermined scenarios. Our results and the fabrication technique presented here will help broaden the current research scope for multiple disciplines and may pave a way to manipulate multiple flows and create new functional devices, e.g., for on-chip applications.

1.4 Reduced interhemispheric functional connectivity of children with autism spectrum disorder: evidence from functional near infrared spectroscopy studies

Autism spectrum disorder (ASD) is a neuro-developmental disorder, which has been associated with atypical neural synchronization. In this study, functional near infrared spectroscopy (fNIRS) was used to study the differences in functional connectivity in bilateral inferior frontal cortices (IFC) and bilateral temporal cortices (TC) between ASD and typically developing (TD) children between 8 and 11 years of age. As the first report of fNIRS study on the resting state functional connectivity (RSFC) in children with ASD, ten children with ASD and ten TD children were recruited in this study for 8 minute resting state measurement.

2. Results in details:

2.1

The performance of a cylindrical radome designed by our method is shown in Fig. 1. Now the shape of our radome is a cylindrical shell with inner radius $R_1=4\lambda_0$ and outer radius $R_2=5\lambda_0$. The whole simulation domain is in a half circle with radius $11\lambda_0$ and the perfect matched layer with thickness λ_0 is chosen as the exterior boundary. An 8×1 PAA, which is the array of line segments with equal length $0.25\lambda_0$ and center to center spacing $d=0.35\lambda_0$, is set along the PEC ground (y' axis). In Fig.1 (a), (b) and (c), a beam with angle 10^o, 20^o and 30^o are produced by the PAA respectively (without our radome). In Fig. 1 (d), (e) and (f), we set a radome with $M=1$ and $\theta_0=45^o$(an angle shifter) after the PAA in (a), (b) and (c) respectively. As we can see the incident beam with angle 10^o, 20^o and 30^o are steered to 55^o, 65^o and 75^o by a fixed angle 45^o shift. Two Parameters M and θ_0 determine the angle compression and angle shifting in our radome.

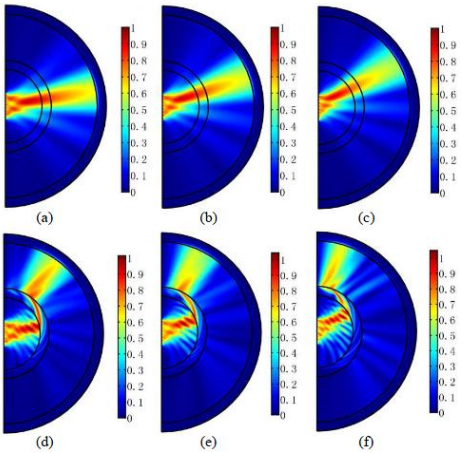

FIG. 1 2D FEM simulation results: the amplitude of the electric field distribution. TE model (the electric field is orthogonal to the x'-y' plane) is chosen here. (a)-(c) without the radome. (d)-(f) with the radome.

2.2

The EMC simulation has been combined with the Huygens–Fresnel principle theory to derive the focal spot of laser beams. Through the hypothesis that the main absorption material in a biological sample between the 800 nm and 2400 nm range is water and the fact that the scattering coefficient can be calculated by the Mie theory, we can obtain the spectra for anisotropic factor, absorption coefficient and scattering coefficient of the biological sample. Using these optical parameters, the intensity distribution of the focal laser beam with different wavelengths in deep tissue can be calculated. Based on our simulation results, 1680 nm is the best pump wavelength for microscopy in deep tissue. In addition, the 2220 nm pump laser is a proper optical source.

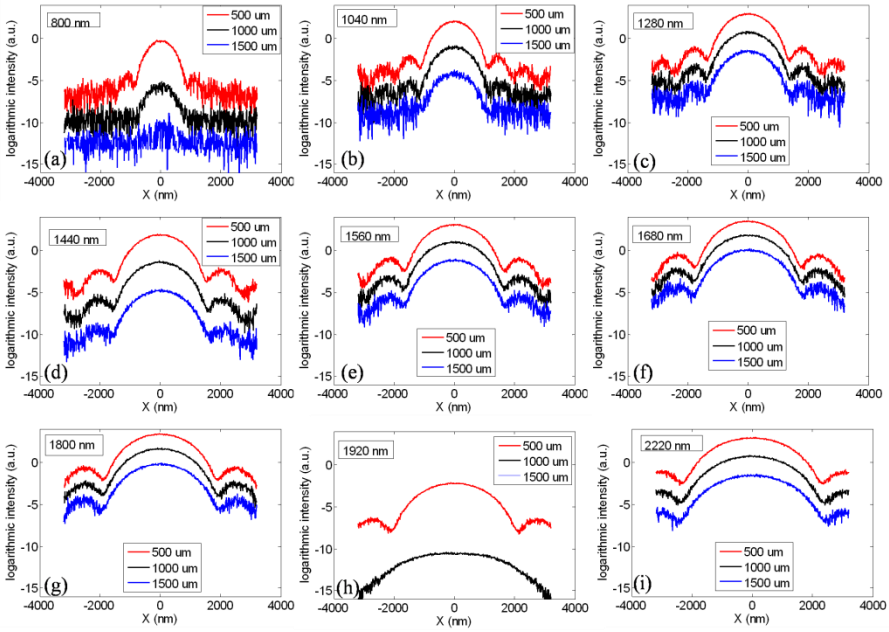

FIG. 2 The intensity curves for the focal spots at depths of 0.5 mm (red curves), 1.0 mm (black curves) and 1.5 mm (blue curves).

2.3

In this Letter we make an experimental attempt to show a multidisciplinary framework that has the capability to simultaneously respond to two different physical excitations according to predetermined scenarios. As a proof of concept, we implement an electric-thermal bi-functional device that can guide both electric current and heat flux “across” a strong ‘scatterer’ (air cavity) and restore their original diffusion directions as if nothing exists along the paths, thus rendering dual cloaking effects for objects placed inside the cavity(see Figure below). This bi-functional cloaking performance is also numerically verified for aline-source non-uniform excitation.

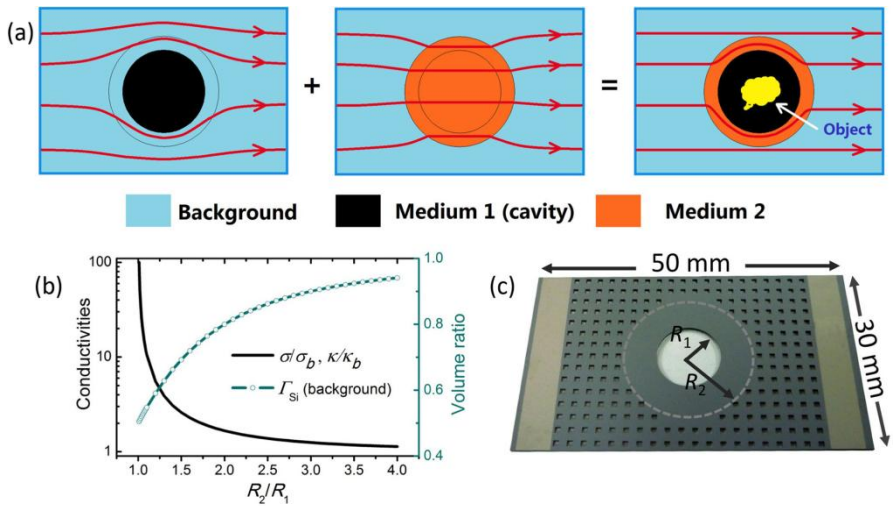

FIG. 3 (a) Schematic diagram of the multiphysics cloak (b) Relative electric and thermal conductivities of the cloak and the silicon volume ratio in the background as a function of the radius ratioR2/R1 of the cloaking shell(c)A photograph of fabricated sample device.

2.4

Compared to TD children, children with ASD showed reduced inter hemispheric connectivity in TC. Children with ASD also showed significantly lower local connectivity in bilateral temporal cortices. In contrast to TD children, children with ASD did not show typical patterns of symmetry in functional connectivity in temporal cortex. These results support the feasibility of using the fNIRS method to assess atypical functional connectivity of cortical responses of ASD and its potential application in diagnosis.

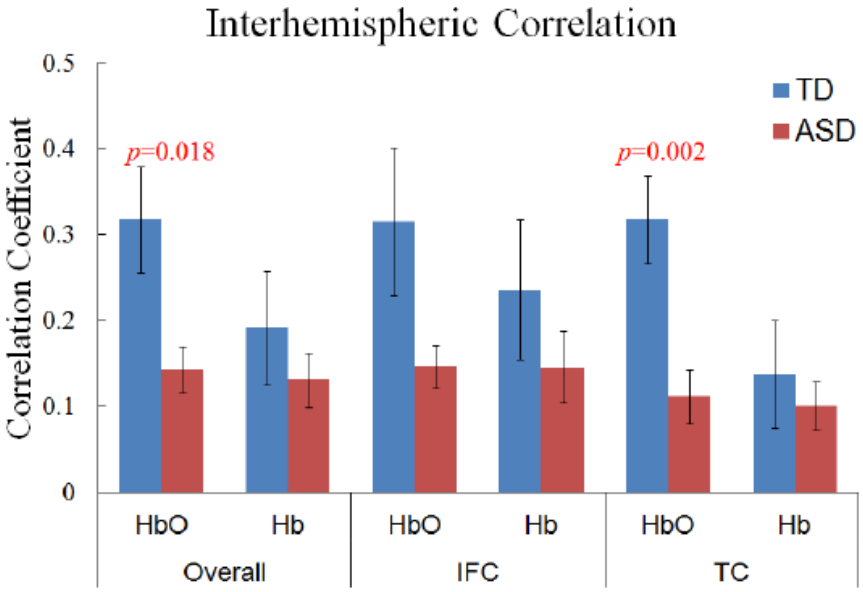

Fig.4. Inter hemispheric correlation in ROIs of children with autism spectrum disorder (ASD, red, n = 10) and typically developing (TD) children (blue, n = 10). Error bars are standard error of mean across participants. Children with ASD showed significantly reduced inter hemispheric correlation in overall (including all the channels, p = 0.018) and temporal cortex (TC, p = 0.002) than TDs in terms of HbO.

3. On-going and future works

In future work, we will try to use optic-null medium to simplify the material requirement of the proposed radome, and study how to realize the optic-null medium by current available materials. We will also study the performance of our radome combined with a practical phased array antenna system.

In the future, we are going to perform nonlinear optical imaging based on 1680 nm. As described in our work, 1680 nm is the best wavelength for deep imaging. Also, 2220 nm is another optional wavelength for bio imaging. We will design and develop a 2220 nm laser for bio-imaging.

An ongoing work is about SERS based bio-detection. It was demonstrated that silver and gold nanoparticles have great capability to enhance Raman signals due to the Localized Surface Plasmon Resonance (LSPR) effect. Comparing these two materials, nanogold has the advantage of perdurable stability and tunable LSPR effect while nanosilver has a bigger scattering cross-section. In this work, gold nanorods and gold nano-echinus were synthesized and immobilized on the glass to form the uniform and robust Surface Enhanced Raman Scattering (SERS) chips. The avian influenza virus was dropped on the gold SERS chip or mixed directly with the nanosilver colloid. After testing, the resultant fingerprints revealed the inner chemical structure of the analyte. Furthermore, Partial Least Squares (PLS) and Principal Component Analysis (PCA) analytical methods were used to classify the virus species, making the classification more accurate. In addition, a rapid, portable and high efficiency Raman testing system was developed to distinguish different types of avian influenza viruses.

Figure1. SEM of Gold Nanoechinus (A). Nano gold colloid and SERS chip (B). SERS spectra of H5N6 virus (C).

List of published journal papers that the present SOARD grant is acknowledged

1). Fei Sun, Shuai Zhang, and Sailing He, "A general method for designing a radome to enhance the scanning angle of a phased array antenna," Progress In Electromagnetics Research, Vol. 145, 203-212, (2014).

2). Fei Sun, and Sailing He, "Transformation inside a Null-space Region and a DC Magnetic Funnel for Achieving an Enhanced Magnetic Flux with a Large Gradient," Progress In Electromagnetics Research, Vol. 146, 143-153, (2014).

3). F. Cai, J. Yu, and S. He, "Vectorial electric field monte caro simulations for focused laser beams (800 nm-2220 nm) in a biological sample," Progress In Electromagnetics Research, Vol. 142, 667-681, 2013.

4). Liu, Yichao; Jiang, Wei; He, Sailing; Ma, Yungui, An efficient plate heater with uniform surface temperature engineered with effective thermal materials, Optics Express, vol. 22, issue 14, p. 17006

5). Ma, Yungui; Liu, Yichao; Raza, Muhammad; Wang, Yudong; He, Sailing,Experimental Demonstration of a Multiphysics Cloak: Manipulating Heat Flux and Electric Current Simultaneously,Physical Review Letters, Volume 113, Issue 20

6). Huilin Zhu, Yuebo Fan, Huan Guo, Dan Huang, and Sailing He, Reduced interhemispheric functional connectivity of children with autism spectrum disorder: evidence from functional near infrared spectroscopy studies, Biomedical Optics Express, Vol. 5, Issue 4, pp. 1262-1274 (2014)

7). K. Liu, W. Jiang, F. Sun, and S. He, "Experimental realization of strong DC magnetic enhancement with transformation optics (invited paper)," Progress In Electromagnetics Research, Vol. 146, 187-194, 2014.

8) H.Zhu, Y. Fan, H. Guo, D. Huang and Sailing He, “Reduced interhemispheric functional connectivity of children with autism spectrum disorder: evidence from functional near infrared spectroscopy studies”, Biomed Opt Express. 2014 Apr 1; 5(4): 1262–1274.

A few other papers are under journal review or in preparation.

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Abstract

The proposed cross-discipline experimental study combines soft material science, laser spectroscopy, nano-technology, biophotonics and multi-physics modeling to produce adaptable bio-nanostructure enhanced multi-mode sensor science. The accomplishments includes

1) A General Method for Designing a Radome to Enhance the Scanning Angle of a Phased Array Antenna.

2)Vectorial Electric field Monte Caro simulations for focused laser beams (800 nm- 2220 nm) in a biological sample.

3) Experimental demonstration of a multiphysics cloak: manipulating heat flux and electric current simultaneously.

4)Reduced interhemispheric functional connectivity of children with autism spectrum disorder: evidence from functional near infrared spectroscopy studies.

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1). Fei Sun, Shuai Zhang, and Sailing He, “A general method for designing a radome to enhance the scanning angle of a phased array antenna,” Progress In Electromagnetics Research, Vol. 145, 203-212, (2014).

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Appendix Documents

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